The Environments of SGRs: A Brief & Biased Review

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ABSTRACT

I review some recent developments in our understanding of the environments of soft gamma-ray repeaters. I pay particular attention to the apparent association betwwen SGR 1900+14 and SGR 1806-20 and embedded clusters of stars.

1. Introduction

The environments of soft gamma-ray repeaters (SGRs) can provide many important insights into these intriguing and unusual objects. First, the environment of an SGR may provide clues to its origins, including possible progenitor stars, the age of the SGR, its space velocity, etc. Such environmental clues may be gleaned from a surrounding supernova remnant, nearby stars, and unusual ISM features, among other things. Secondly, by studying the impact of the SGR on its surrounding ISM (or vice versa) we can also hope to learn more about the evolution of SGRs.

In this review, I will first go over what we knew (or thought we knew) about SGR environments previously. I will then go over our current state of knowledge regarding the environments of SGRs which are well-localized at the time of the Woods Hole 2001 meeting: SGR 0525-66, SGR 1900+14, and SGR 1806-20.

2. What We Used to "Know"

Prior to about 1998, the community had a reasonably clear (though not universally accepted) picture of SGR environments. The three well-localized SGRs were all "known" to be associated with supernova remnants. SGR 0525-66 lies inside the supernova remnant N49 in the LMC (Rothschild, et al. 1994). SGR 1900+14 was localized to within a few arcminutes of G42.8+0.6 (Hurley, et al. (1994); Vasisht, et al. (1994)), and also apparently coincident with an unusual double MIa star system (Vrba et al. 1996). Finally, SGR 1806-20 was found to lie very close to the apparent SNR G10.0-0.3 (Hurley, et al. 1994). This supposed SNR

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had a bright, variable radio core apparently associated with an X-ray source (Vasisht et al. (1993); Kulkarni & Frail (1993)), indicating a possible plerionic SNR similar to the Crab Nebula. Subsequent observations revealed a bright heavily-absorbed infrared star at the radio core position (Kulkarni et al. 1995), which was then found to be a candidate luminous blue variable (LBV) star based on its IR spectrum (van Kerkwijk et al. 1995). Due to the extreme rarity of both LBVs ans SGRs, a chance superposition of these two seemed very unlikely and led to the conclusion that the SGR must be related to the LBV. As I describe below, we now recognize that many of these associations are either coincidental or due to some more complicated underlying associations.

3. SGR 0525-66

Since the giant outburst of March 1979, SGR 0525-66 has been associated with the Large Magellanic Cloud (Mazets et al., 1979). More recently, Rothschild, et al. (1994) found an X-ray source within the γ-ray error box, which lies inside the contours of the N49 SNR. Simple analyses show that the chance projection of the SGR within this SNR is $< 1\%$, even making rather stringent assumptions (Gaensler et al. 2001). Thus, this SGR/SNR association seems robust.

SGR 0525-66 and its host SNR also have the lowest extinction of any known SGR, with $A_V \sim 1$ mag. More recently, Kaplan et al. (2001) have obtained HST optical observations of the area surrounding SGR 0525-66. They find several stars within the X-ray positional error box, as well as some apparent bright "lumps" from the SNR itself. The stars are consistent with G/K main sequence stars. It is interesting to note, in comparison with the other well-localized SGRs, that there are **no luminous stars nearby**.

4. SGR 1900+14

The γ-ray IPN localization for SGR 1900+14 initially led to an apparent association with an X-ray source (Hurley, et al. 1994). This in turn led to an initial optical/IR identification of SGR 1900+14 with an unusual pair of M-type supergiant stars (Vrba et al. 1996). The relative scarcity of such pairings made a coincidental alignment of the SGR with them moderately unlikely.

However, the 1998 major outburst of SGR 1900+14 produced, among other things, a radio transient which Frail et al. (1999) localized to $\sim$ 1-arcsec precision. This position was shown to be inconsistent with the M-star pair (Eikenberry & Dror 2001) (see Figure 1), and

no variable source was found from IR observations during the 1998 flare (Oppenheimer et al. (1998); Eikenberry & Dror (2001)).

More recently, Vrba et al. (2000) have shown that the M-star pair are in fact the two brightest members of an entire cluster of supergiant and giant stars. This dense cluster has a reddening consistent with the X-ray absorption towards SGR 1900+14, and, at an assumed distance of $\sim 10 - 15$ kpc, lies a projected distance of ~ 1 pc from the SGR. The same arguments apply for the association with the SGR and the cluster – the odds of having two such unusual objects coincidentally aligned on the sky are low. One possible interpretation is that SGR 1900+14 was "born" in the cluster of stars, and either left in its progenitor stage or was ejected by a supernova kick (or both). If we assume this scenario and a "standard" pulsar kick velocity of a few hundred km/s, then a separation of 1 pc implies an age for SGR 1900+14 of $< 10^4$ years – consistent with several models for SGR activity.

5. SGR 1806-20

As noted above, SGR 1806-20 was thought to be associated with a luminous blue variable (LBV) star which lies at the time-variable (in both flux and morphology) core of the radio nebula G10.0-0.3 (Vasisht et al. (1993); Kulkarni & Frail (1993)). However, the recent Inter-Planetary Network (IPN) localization of SGR 1806-20 provides a position inconsistent with that of the LBV star and radio core (Hurley et al. 1999c). Furthermore, Gaensler et al. (2001) argue that G10.0-0.3 is not a supernova remnant at all, but is rather powered by the tremendous wind of the LBV star. Infrared observations of the field of SGR 1806-20 reveal that the LBV star is not alone, but appears to be part of a cluster of embedded, hot, luminous stars (Fuchs et al. 1999), and the IPN position for SGR 1806-20 is consistent with membership in that cluster. Recently, Eikenberry et al. (2002) have used near-infrared photometry and spectroscopy to conclude that this cluster contains what may be the most luminous star in the Galaxy (the LBV star), at least one Wolf-Rayet star of type WCL, and at least two blue "hypergiants" of luminosity class Ia+. These properties make the cluster resemble a somewhat smaller and older version of the "super" star cluster R136 (Massey & Hunter 1998), making the potential association with SGR 1806-20 even more intriguing.

Chandra observations of SGR 1806-20 have provided a sub-arcsecond localization of the SGR in this crowded field (Kaplan et al. (2002); Eikenberry et al. (2001)). The localization matches the IPN position for SGR 1806-20, and completely excludes a direct association of the SGR with the LBV and radio core. This seems to confirm the conclusion of Gaensler et al. (2001) that G10.0-0.3 is in fact not a SNR, but is instead a radio nebula powered by the mass-loss wind of the LBV star at its core. Figure 2 shows J-, H-, and K-band infrared

images taken with OSIRIS on the CTIO 4-m telescope of the region near SGR 1806-20, along with the 90% positional error circle. As noted above, SGR 1806-20 lies in the direction of an unusual embedded cluster of massive, luminous young stars (Fuchs et al. (1999); Eikenberry et al. (2002)), with a distance of 14.5 ± 1.4 kpc and a reddening of $A_V = 29 \pm 2$ mag (Corbel et al. (1997); Eikenberry et al. (2002)). The fact that stars D and E in Figure 2 have $J - K = 5.0$ mag indicates that they are members of this cluster ($E_{J-K} = 5.0$ mag for $A_V = 29$ mag), and thus that SGR 1806-20 lies within the radial extent of the cluster on the sky. Furthermore, the X-ray absorption towards SGR 1806-20 is $\sim 5 - 6 \times 10^{22}$ cm^{-2} (see above, and Mereghetti et al. (2000)), which is consistent with the extinction towards the cluster. Thus, it seems likely that SGR 1806-20 is also a member of this massive star cluster at a distance of 14.5 ± 1.4 kpc.

The IR colors (and upper limits) of the two candidate counterparts to SGR 1806-20 are consistent with both of them being stellar members of the star cluster ($J - K = 5.0$ mag, $H - K = 2.0$ mag). Note that the brighter star just outside the error circle ("C" in Figure 2) appears to be a foreground star ($J - K = 3$ mag), confirming that it is not a likely counterpart to the SGR. However, as can been seen in Figure 2, the field of SGR 1806-20 is highly crowded in the IR by both foreground/background objects and cluster members, and the simple fact that two stars lie within the 90% confidence error circle and another just outside it shows that the probability of a chance coincidence of unrelated IR objects is high. Thus, we cannot conclude definitely that *either* of the possible counterparts is actually related to SGR 1806-20. If both candidates are in fact members of the cluster, we can estimate their absolute magnitudes to be $M_K = -2.3$ mag (A) and $M_K = -0.4$ mag (B). For Star A, this is consistent with stars of luminosity matching a B1V or K3III star, and is inconsistent with any stars of luminosity class I. After correcting for the $H - K = 2$ mag differential extinction toward the cluster, the intrinsic color of $(H - K)_{intrins} = 0.8 \pm 1.2$ mag is essentially consistent with all stellar spectra earlier than late M, and does not significantly constrain the classification. For Star B, the absolute magnitude is consistent with stars of luminosity matching a B8V star, and is inconsistent with any stars of luminosity class III or higher. It is important to note that no observations have yet probed the distribution of stars in the cluster with masses below that of late B main sequence stars. Thus, it is possible that there are even further stars within the error circle at significantly lower mass/luminosity, unless the cluster mass distribution shows a sharp lower cutoff.

One particularly intriguing aspect of the association between SGR 1806-20 and the star cluster is that a neutron star progenitor went supernova *before* the stars currently observed in the cluster. Since more massive stars evolve to the supernova stage more rapidly, *if* the progenitor of SGR 1806-20 formed at the same time as the currently observed massive stars, its mass must have been greater. However, the mass estimate for the LBV is $> 200 M_{\odot}$

(Eikenberry et al. 2002), and several of the other stars are likely to have masses in the range of $\sim 50 - 100 M_{\odot}$ (Eikenberry et al. 2002). While recent theories have predicted that very massive stars may produce neutron star remnants due to the effect of envelope loss via dense stellar winds, the upper limit on their masses is $\sim 80 M_{\odot}$, with higher mass stars producing massive black hole remnants. Thus, it seems unlikely that the SGR 1806-20 progenitor formed at the same time as the currently observed massive stars in the cluster.

Alternately, SGR 1806-20 may have formed prior to these stars – in fact, Kaplan et al. (2002) suggest that the supernova event that produced SGR 1806-20 may have triggered the star formation activity that produced the massive stars in the cluster. However, the massive stars we observe in the cluster are evolved, with ages of $\sim 10^6$ yr to reach the LBV and Wolf-Rayet stages of their lives. If the SGR 1806-20 supernova event led to the birth of these stars, then SGR 1806-20 is much older than the $\sim 10^3 - -10^4$ yr typically considered for magnetars. Alternately, SGR 1806-20 may simply be taken as evidence for prior massive star formation at this location. While at least one supernova occurred here, perhaps it was not the first, and an earlier supernova event triggered the formation of the currently observed massive stars.

6. Some Conclusions

Here I present some of the conclusions of the above discussions:

- Of the well-localized SGRs, only SGR 0525-66 seems to have a clear association with a SNR.
- SGR 1900+14 is not *directly* associated with the MIa double star system.
- SGR 1806-20 is not *directly* associated with the LBV star near it, nor is there a SNR evident in this neighborhood
- Both SGR 1806-20 and SGR 1900+14 are in/near dense clusters of massive stars. These are rare enough that a chance superposition is low.
- The association of SGRs with such clusters explain the apparent, but eventually false, association with some of the particular massive stars in the clusters.
- SGR 0525-66 is *not* associated with any apparent cluster of massive stars.
- Th environments of SGRs are giving some very interesting, if somewhat mixed, signals regarding the origins and evolutions of these objects.

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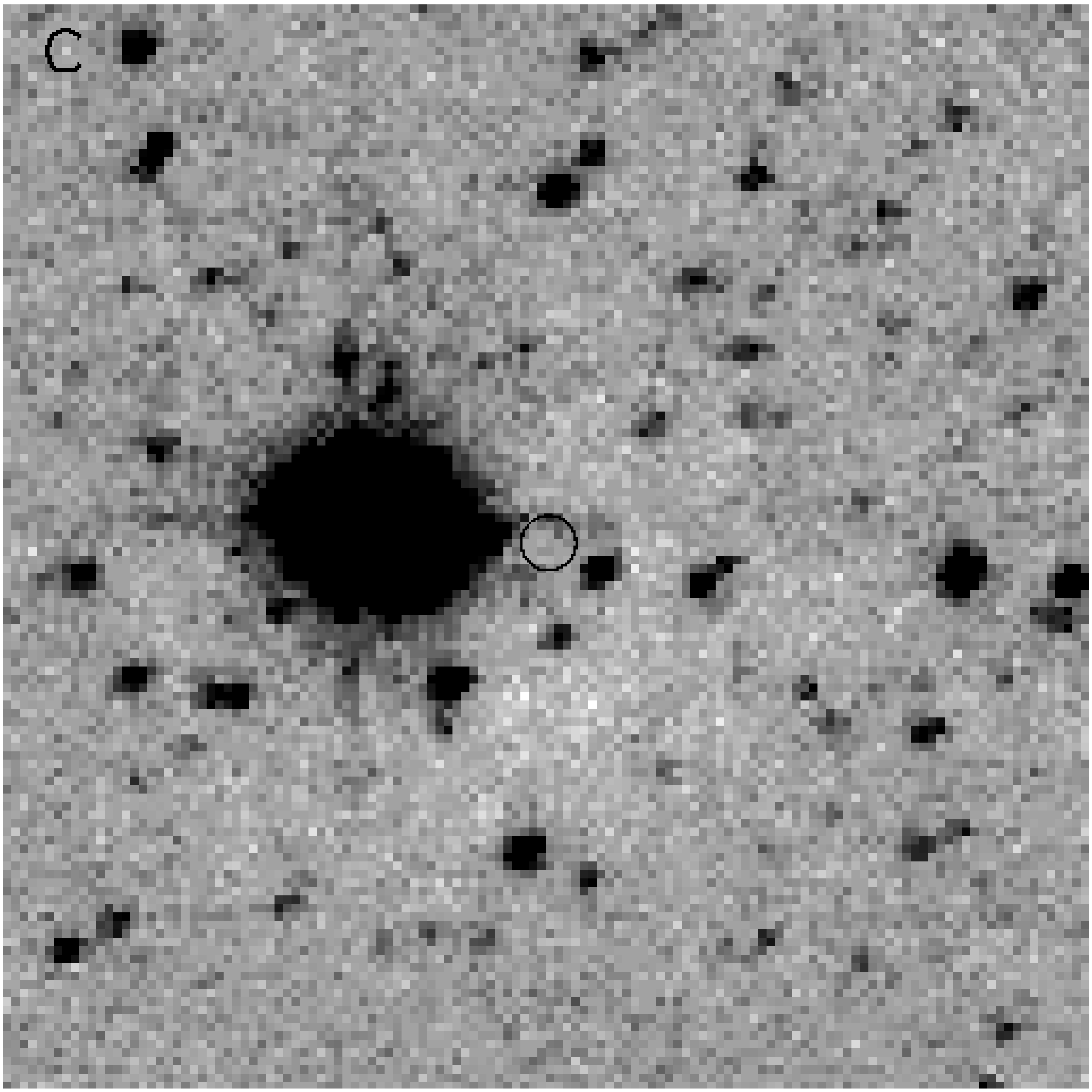

Fig. 1.— Infrared K-band image of the field near SGR 1900+14 taken near the outburst of 1998 (after Eikenberry & Dror (2001)). The small circle indicates the radio positional error box for SGR 1900+14. The cluster of stars including the luminous M-star pair are seen off to the left. North is up and east is to the left in this image.

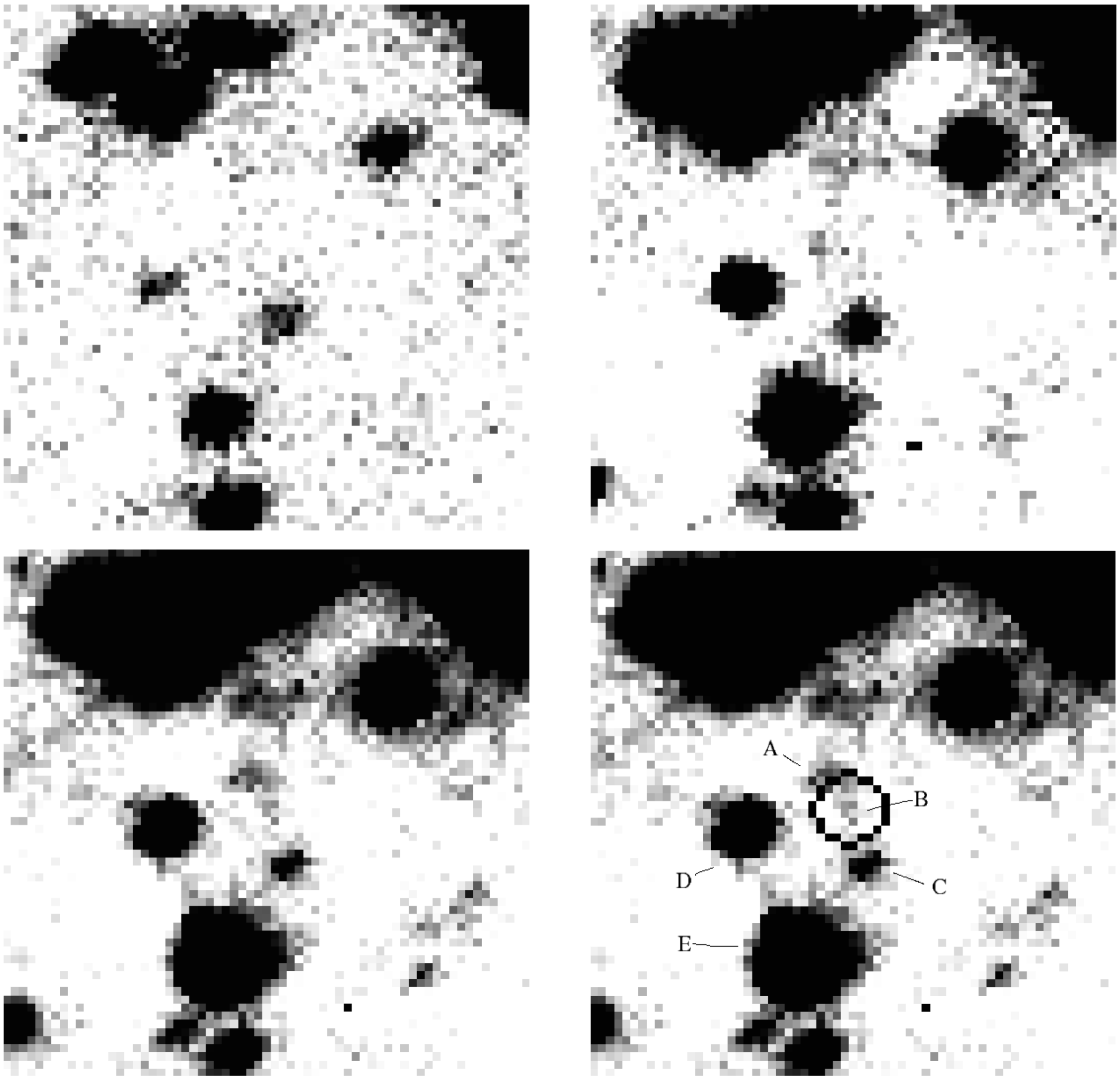

Fig. 2.— Infrared images of the field of SGR 1806-20 (as in Eikenberry et al. (2001)). Images shown are: J-band (top left); H-band (top right); K-band (bottom left); K-band with stars labelled (bottom right). North is up and east is to the left. The circle indicates the 0.7-arcsec-diameter X-ray error circle from *Chandra*. The bright stars at the top of the images are near the cluster center.